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Modern Continuous Samplers for Volatile Organics and Inorganic Gases

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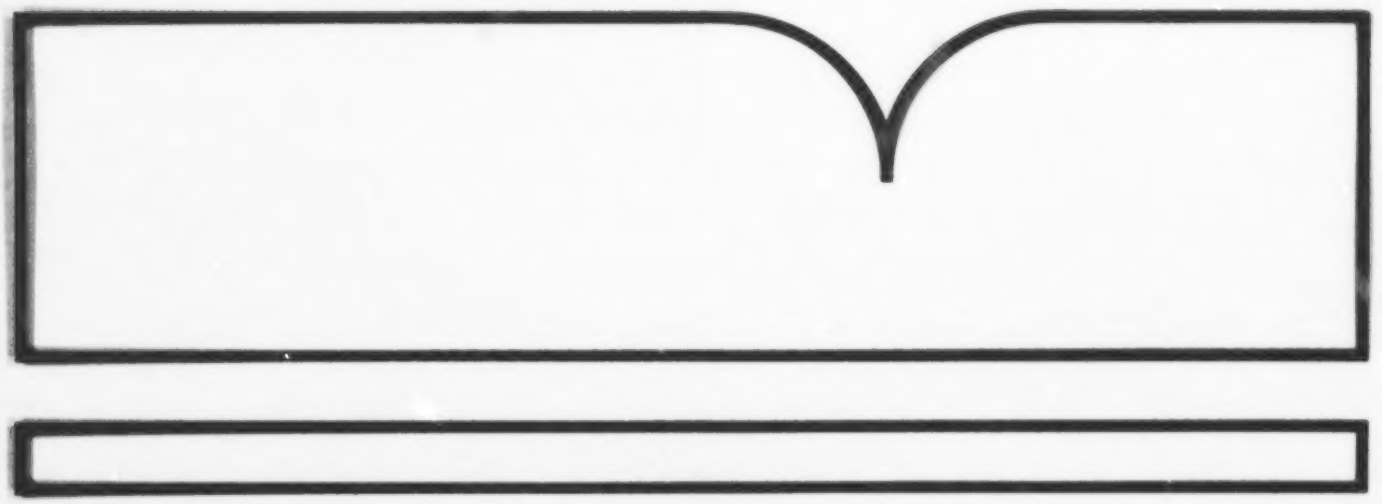

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16. ABSTRACT

This manuscript discusses EPA methods development in two areas: VOC monitoring and monitoring of dry depositon components. Whole air collection over periods of up to one day in specially prepared stainless steel canisters is beginning to be used routinely for volatile organic compounds (VOCs), although the use of solid adsorbents like Tenax® is still the primary means for collection. Selective accumulation of target species in increasingly concentrated form as sampling time increases, as for collection of ambient particulate matter, or for capture of target gases on a specially prepared surface, is being used for sampling dry deposition components over periods of up to one week.

Canister-based sampling systems and distributed air volume (DAV) sets of Tenax®-packed cartridges have been compared for indoor air samples. Ten VOCs were monitored during ten 12-hour sampling runs. The average value of the slope of the linear regression of Tenax® mean versus canister mean was 0.95, while slope values for individual compounds varied from 0.80 ± 0.06 to 1.10 ± 0.17. Similar outdoor air study results showed a significant deterioration in agreement. Currently three versions of dry deposition samplers are being compared and evaluated. These are the filter pack, transition flow reactor, and the annular denuder system. Results from EMSL comparison studies during the fall of 1986 show surprisingly good agreement among all three.

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MODERN CONTINUOUS SAMPLERS FOR VOLATILE ORGANICS AND INORGANIC GASES

by

William Arthur McClenny and Richard J. Paur
Environmental Monitoring Systems Laboratoty
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

EPA Project Officer
William A. McClenny

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

Abstract

New types of ambient air and indoor air samplers are under development for use in network and special study applications for the Environmental Monitoring Systems Laboratory, U. S. E.P.A. These samplers provide continuous collection at constant rates over the sampling period by actively moving ambient air to the collection volume (or surface). Whole air collection over periods of up to one day in specially prepared stainless steel canisters is beginning to be used routinely for volatile organic compounds (VOCs), although the use of solid adsorbents like Tenax® is still the primary means for collection. Selective accumulation of target species in increasingly concentrated form as sampling time increases, as for collection of ambient particulate matter, or for capture of target gases on a specially prepared surface, is being used for sampling dry deposition components over periods of up to one week.

Canister-based sampling systems and distributed air volume (DAV) sets of Tenax®-packed cartridges have been compared in both indoor and outdoor studies. For indoor air samples, ten VOCs were monitored during ten 12-hour sampling runs. The average value of the slope of the linear regression of Tenax® mean versus canister mean was 0.95, while slope values for individual compounds varied from 0.80 $\pm$ 0.06 to 1.10 $\pm$ 0.17. Similar outdoor air study results showed a significant deterioration in agreement.

Currently three versions of dry deposition samplers are being compared and evaluated. These are the filter pack (FP), transition flow reactor (TFR), and the annular denuder system (ADS). Results from EMSL comparison studies during the fall of 1986 show surprisingly good agreement among all three.

Introduction

The scientific effort within EMSL, U.S. EPA for development and evaluation of new and improved methods for monitoring air quality has been driven by interest in three main topics: toxics, acidic deposition and indoor air quality. Reliable instrumentation for EPA's monitoring networks and for special studies are needed to obtain data bases from which to distill information relevant to regulatory and scientific questions being addressed by the agency.

An example from the toxics area is the fledgling Toxic Air Monitoring System (TAMS) network. This network currently consists of two sites at each of three cities, Houston, Boston and Chicago, with plans in 1987 for an additional site in each city and one site in a fourth city. Each site has 24-hour sampling systems for volatile organic chemicals (VOCs). Samples are collected on a 12 day schedule and then returned to EPA's central laboratories at the Research Triangle Park, NC for analysis and data archival. Solid sorbent sampling using Tenax® is used at every site while two canister-based samplers are also used at one of the Houston sites. Samples are taken by sampling at constant rates over 24 hour sampling periods. Special projects in toxics monitoring includes the upcoming TEAM (total exposure assessment monitoring) study in Baltimore. As part of this study, twelve-hour samples will be taken inside and outside selected residences using weatherized canister-based samplers outside and simpler units inside.

The central question for sampling VOCs is whether to continue using Tenax® solid sorbent or to switch to the use of specially prepared canisters for sample collection and storage. The existence of sampling problems with Tenax® has been documented and explored by Walling et al. (1) of the U.S. EPA,

and he has devised a sampling approach using Tenax®, the distributed air volume (DAV) approach (2), that is a screening procedure to eliminate questionable results. Unfortunately, the fraction of data eliminated is high, varying from 40% to 60%. Specially prepared containers for whole air collection and storage of VOCs were used in the early 1970's by air quality researchers at Washington State University. A proprietary electro-polishing solution was developed for treating the interior surfaces of the canisters and special procedures are observed in welding together hemispheres to form the container. Today the canisters can be purchased as off-the-shelf items from either of two small companies. The most common size is the six-liter, spherical canister. The canisters are cleaned and evacuated to a small fraction of a torr prior to use. Typical usage includes sampling for hydrocarbons in ambient air, either for individual organics (3, 4) or for nonmethane organic compounds (NMOCs) as part of a recent effort by EPA and state agencies to establish the reduction of hydrocarbon emissions necessary to reach acceptable ambient ozone concentrations (5). The current emphasis on the use of canisters is associated with the extension of their usefulness to include collection of toxic VOCs, including substituted hydrocarbons such as vinyl chloride, ethylene oxide, methylene chloride and tetrachloroethylene.

The development and evaluation effort in acidic deposition is mainly associated with the selection of instrumentation for sampling dry deposition components for use in the 100-station national network to be implemented through an EMSL contractual effort. Specifically, the factors influencing selection of

sampling units designed for week-long multi-component collection are being considered. Central among these factors are accuracy, artifact-free collection, reliability and expense. The chemical collection of inorganic gases by bonding reactions with surface coatings or selected surface materials is being studied using different sampling formats. These involve sampling targeted air components on surfaces placed perpendicular to the mass flow direction or on surfaces placed parallel to the mass flow direction. In the latter case, particles and gases can be separately collected based on the differences in diffusion, i.e., gases diffuse rapidly to the sampler wall and can be collected there. Particles are collected downstream on size-exclusion filters. However, this convenient separation dramatically alters the phase equilibrium at the filter and causes particle to gas conversions. Chief among the candidate sampling units are: (a) the filter pack system (usually referred to as the Canadian filter pack because of their extension usage (6); (b) the transition flow reactor (TFR), (7,8); and (c) the annular denuder system (ADS) as altered from the earlier Italian version (9) to meet dry deposition monitoring constraints (10). All the units use filter packs and draw air through the collection system by use of air pumps. The addition of equipment to separate gases from particles to the simpler filter packs adds the possibility of serial and separate collection of groups of gases having different chemical bonding characteristics, e.g., acidic versus basic groups.

Discussion

Volatile organic samplers

The use of distributed air volume (DAV) sets is the current EPA sampling approach. Four sampling channels are established each with a different sampl-

ing rate, typically resulting in 24 hour sample volumes of 5, 10, 20 and 40 liters. The amounts of VOCs collected divided by the respective sample volumes should give answers that are reasonably equivalent to duplicates. If not, sample integrity is compromised and the data is invalidated. Standard operating procedures for sampling and analysis of air samples using a Tenax® solid sorbent are available from EMSL (11). Since the solid sorbent is the first element in the sampling train, contamination does not occur from upstream sampler components. However, passive sampling can occur if the cartridge channel is exposed and is a potential source of error depending on the duration of unpumped exposure time and the effective passive sampling rates. In typical sampler designs, electronic flow controllers are used to establish a constant flow rate through the Tenax®. The DAV has been used by the U. S. EPA in controlled laboratory experiments and in a number of field studies to determine any problems. The DAV itself performs as expected to screen samples but does not identify the cause of questionable data and, although some of the potential problems with Tenax® are documented, their definition does not make the occurrence of artifacts predictable. Indeed, results vary with location and time in an apparently random manner.

Canister-based samplers (12) allow for several sampling train configurations, since the evacuated canisters can be used to pull in sample air without need for any external power source. Subject to sampling location, a simple combination of particulate filter, critical orifice and canister can be used to obtain a reasonably constant sampling rate until the canister pressure exceeds the level necessary to maintain a critical flow, i.e., one-half atmosphere.

The substitution of an electronic flow controller for a critical orifice allows extension of the period over which a constant sampling rate can be maintained. This configuration has been used to sample for approximately 24 hours into a six-liter canister, using flow rates of less than 5 cc/min. Using the canister vacuum to produce flow results in a sample at sub-atmospheric pressure at the end of the sampling run. To supply an excess flow at the analytical system inlet, the canister can either be pressurized by a zero gas so that the diluted canister contents can be vented past the system inlet, or the canister contents can be transferred through the analytical system (reduced temperature VOC trap) into a canister at lower pressure until a given pressure increase in the receiving canister is recorded. The canisters are also used with sampling trains that include filter, flow controller, pump, and canister, so that the canister is pressurized during collection. These components are often enclosed in a temperature regulated, weatherized housing for operation outside. The weatherized canister systems have been used in a number of field studies, including the following.

Kanawha Valley Toxics Evaluation Study (KVTE):

Canister-based samplers in weatherized housings were initially constructed, tested and employed as part of the KVTE Study in the winter of 1985-86. The sampler design schematic is shown as Figure 1. Tentative operating procedures for sampling and one for analysis of samples were prepared and were used in the KVTE study. The samplers were tested prior to deployment by ambient air sampling comparison runs. These tests showed general agreement for

all compounds (within 0.3 ppbv for concentrations of 5 ppbv or less and within 10% for higher concentrations) except for one sampler which showed ppb losses in some cases. Five samplers were deployed in the Kanawha Valley at four sites with the extra sampler being rotated among the remaining four to establish an additional measure of quality control. This procedure identified results from one sampler as consistently low for the higher molecular weight compounds. This was the same sampler that gave consistently low readings in the earlier tests. Systematic cleaning of the sampler components has subsequently minimized losses.

Audit runs during the KVTE study using a set of reference compounds in dry nitrogen showed that higher molecular weight compounds were significantly reduced in concentration upon passage through the samplers and that they reappear in subsequent samples taken from the ambient air. The same behavior was repeated after the samplers were returned to EMSL, i.e., the heavier VOCs in audit runs were held up in the sampler and subsequently returned to the air stream when a humidified sample was pulled through the sampler. No such behavior was noted when the audit sample was humidified.

The sample performance during audits suggests that water vapor usually occupies adsorption sites otherwise active with respect to some volatile organics. If water vapor is not present, volatile organics are at least delayed during passage through the sampler because of increased adsorption. When next a humidified air stream is passed through the sampler, water vapor appears to displace the adsorbed VOCs which then show up as false positive concentrations.

Although this explanation is consistent with our experimental evidence, no direct proof has been obtained. Subsequent to the KVTE, sampler component cleaning procedures have been implemented that minimize the adsorption of VOCs from dry air streams.

Conclusions from KVTE:

1. Better quality control procedures in selection and cleaning of components during assembly of sampler components.
2. The audit procedure should be carried out with humidified audit gas or the sampler component on which the heavier VOCs stick must be identified and replaced.

California Air Resources Board (CARB) Summer 1986 Study

EMSL participation in the CARB summer study consisted of a Battelle Columbus task assignment to operate three samplers and one Tenax® DAV at the study site (campus of Citrus College) and to analyze a portion of the samples. This portion was the 12-hour daytime samples taken over the nine-day sampling period and consisted of the Tenax® DAV set and two duplicate canister samplers of the modified Kanawha Valley type (K-type). Northrop Services, the EMSL in-house contractor, analyzed the nighttime samples which consisted of two duplicate canister samples from the modified K-type samplers and canisters from a sampler donated by Dr. Rei Rasmussen of the Oregon Graduate Center. The Rasmussen sampler (R-sampler) is designed differently as shown in Figure 2. Air is pumped into the sampling train at a high rate to a "dump cross" equipped with an adjustable leak. Most of the sample is dumped and the upstream volume is

pressurized. A mechanical flow controller is adjusted to give the correct flow rate for up to 24 hour runs. The pressure difference between the upstream and downstream sides of the flow controller has to be maintained above a minimum value.

The initial results of the CARB study showed that the modified K-type samplers have contamination from Freon 113 and tetrachloroethylene, with possible deletion of trichloroethylene. Daytime samples showed higher contamination presumably because of higher temperatures causing higher emission rates from contaminated materials. Freon 113 and tetrachloroethylene contamination was traced to emissions from a section of Teflon-lined stainless steel tubing. The R-type sampler was apparently free of contamination and deletions. Its only problem appears to be the collection of water in the section of high pressure between the pump and flow control element.

Conclusions from CARB Summer Study:

1. High temperatures typical of summer conditions should be used to test samplers for the outgassing type of contamination. More rigid component selection and cleaning procedures are warranted.
2. R-type sampler components are apparently free of target gas contamination and of deletion problems.

Houston Toxic Air Monitoring System (TAMS):

Two modified K-type samplers were supplied for use in the Houston TAMS "research" site. The modification consists of adding a second pump to draw sample air through the heated inlet at a higher flow rate so that the inlet

becomes an inlet manifold. Sample is drawn into the flow controller from the inlet manifold at a low rate compatible with 24-hour sampling duration. The samplers operate to collect 24-hour samples every 12 days. For the first eleven sets nine of the duplicate canister sample analyses show generally good agreement, but also show the same problems as the CARB samples. Two of the sets showed a systematic disagreement between the duplicate canister sample analyses that has yet to be resolved.

Conclusions from Houston TAMS:

1. Unattended operation of the samplers in duplicate usually shows results equivalent to the CARB study but under Houston conditions.
2. A high degree of maintenance is apparently not required for the modified K-type samplers.

Tenax® DAV and Canister Sampler Comparisons

An indoor air study comparing Tenax® sorbent collection with canister collection was carried out in the summer of 1985 in a furnished, unoccupied residence in Columbus, Ohio for ten 12-hour sampling periods. The canister-based sampler consisted of an assembly of individual components in a "K-type" sampling train and Tenax® DAV sets were used. The indoor air was spiked with a set of ten VOCs which were added to the ventilation system at the return air intake. These ten compounds are: (1) chloroform; (2) 1,1,1-trichloroethane; (3) benzene; (4) bromodichloromethane; (5) trichloroethene; (6) toluene; (7) tetrachloroethene; (8) styrene; (9) p-dichlorobenzene; (10) hexachlorobutadiene. The concentrations for each compound varied by at least an order of magnitude in the 0-10 ppbv range. Comparison of 12 analytical results using the two

sampling techniques is shown in Figure 3 as the slope of the linear regression plus and minus one standard error. The average value of the slope is 0.95 even including the lighter compounds. The sample volumes for the lighter compounds are expected to exceed the retention volume of the sorbent and thus to give a slope biased towards lower values. The methods of collection are assumed to be equivalent if: (a) a detailed statistical analysis showed that for the DAV, the slopes adequately represent the experiment and (b) the slope and intercept estimates are within two standard errors of one and zero, respectively. Under these conditions, compounds (3), (6), (7) and (9) qualify. Compound (8) violates the intercept constraint. Compounds (1), (2) and (10) do not satisfy the condition (a). Compounds (4) and (5) as well as (1) and (2) violate the slope constraint. The average ratios for the individual compounds are shown in Table 1; R_1 is listed to show results if only the low volume collection tube is used. A more detailed discussion is given by Spicer et al. (13).

A similar comparison study but monitoring ambient air was performed in the summer 1986 study sponsored by the California Air Resources Board, as noted above. Only 1,1,1 trichloroethane and toluene had a sufficient concentration range to warrant a linear regression analysis. Slope values $\overline{R}$ and $\overline{R}$, for Tenax® results regressed on canister results are shown in Table 1 for the nine sampling periods. Toluene concentrations ranged from 3-7 ppbv, while 1,1,1 trichloroethane concentrations ranged from 1-4 ppbv. Intercept values for toluene plus and minus one standard error were 0.86 $\pm$ 0.46 ppbv for the full DAV set and 1.80 $\pm$ 0.90 ppbv for single tube Tenax®. For 1,1,1 trichloroethane the intercept values were 0.02 $\pm$ 0.15 ppbv and -0.09 $\pm$ 0.18 ppbv.

Table 1 - Comparison of Tenax® DAV Results and Canister Results

Compound Name	Indoor Air		Outdoor Air	
	$\bar{R}$*	R_1**	$\bar{R}$*	R_1**
Chloroform	0.80 ± 0.03	1.02 ± 0.07	--	--
1,1,1-Trichloroethane	0.86 ± 0.03	1.06 ± 0.06	0.82 ± 0.05	1.02 ± 0.07
Tetrachloroethene	1.10 ± 0.09	1.17 ± 0.12	--	--
Bromocichloroethane	0.86 ± 0.02	0.92 ± 0.04	--	--
Trichloroethene	0.92 ± 0.02	0.95 ± 0.04	--	--
Benzene	1.08 ± 0.14	0.97 ± 0.16	--	--
Toluene	1.03 ± 0.06	1.10 ± 0.09	0.62 ± 0.09	0.50 ± 0.18
Styrene	0.93 ± 0.04	0.96 ± 0.05	--	--
p-Dichlorobenzene	0.99 ± 0.05	1.03 ± 0.05	--	--
Hexachlorobutadiene	0.97 ± 0.04	0.91 ± 0.04	--	--

* $\bar{R}$ - Slope of linear regression analysis, Tenax® vs. Canister, using average result of DAV set, ± one standard error.

** R_1 - Slope of linear regression analysis, Tenax® vs. Canister, using low volume collection tube in the DAV set, ± one standard error.

Discussion - Inorganic Samplers

EMSL has the mandate within EPA to identify and/or develop a multi-component sampler for use in a nationwide deposition network. The latest efforts have been directed towards the comparison of a number of samplers in a two-week study at one of the six stations (the Research Triangle Park, NC location)

currently operating in the network. The comparison involved thirteen consecutive 24 hour collection periods. Approximately 95% successful data capture occurred. Of particular importance to EPA was the comparison between the filter pack (FP), annular denuder system (ADS) and transition flow reactor (TFR), since each is a candidate for providing the multicomponent sampling in the dry deposition network. To facilitate a comparison, analyses of samples from these three methods were performed by the same laboratory. Field blanks, duplicate samples, periodic flow measurements and other quality assurance features were included as part of the tests. Four of the methods operated during the study and the species monitored are given in Table 2.

Table 2 - Species Monitored at the EMSL 1986 Methods Comparison Study

Species	ADS	TFR	FP	TDLAS
NO_2		✓		✓
SO_2	✓	✓	✓	
HNO_3	✓	✓	✓	✓
NH_3	✓	✓		
SO_4^{2-}	✓	✓	✓	
NO_3^-	✓	✓	✓	
NH_4^+	✓	✓	✓	
HNO_2	✓			

Also, a tunable diode laser system (TDLAS) provided reference measurements for nitric acid and nitrogen dioxide. Since the TDLAS measurements consist of monitoring absorption features of these gases in the infrared portion of the spectrum, the TDLAS is considered to provide unambiguous identifications.

Research Triangle Institute personnel performed sampling and analysis for the ADS and TFR systems as well as the analysis for the FP system. Atmospheric Environment Service (Canada) personnel sampled using the FP. Unisearch Associates (Canada) personnel provided the TDLAS measurements. Atmospheric Sciences Research Laboratory (U.S. EPA) personnel provided additional TFR comparisons.

Although the data analyses for the study is only partially done, some preliminary results are now available. These results can be summarized as follows. The designation RTI-TFR refers to a nonstandard interpretation of the TFR data. The characterization of two methods as being equivalent means that on a statistical basis no difference could be shown at a 95% confidence level. The word "total" describing nitrate denotes nitrate extracted from the cyclone inlet on either the ADS or TFR plus the sum of gaseous and particle nitrate found elsewhere in the sampler. The word "total" describing ammonium denotes the sum of ammonium found on the cyclone inlet to either the ADS or TFR plus the ammonium found on the Teflon filter collection surfaces.

Daily samples

1. Total nitrate and total particulate sulfate results from samples taken with the three multicomponent samplers are statistically equivalent.
2. Nitric acid results from samples taken with FP and ADS systems are equivalent to the TDLAS reference measurements. One of the TFR systems was consistently much too high, although a nonstandard interpretation of the TFR data gave better agreement. A second independent TFR system was close to but slightly higher than the consensus, although it was used in only five of the thirteen sampling periods.
3. Nitrogen dioxide measurements from TFR samples are equivalent to TDLAS reference measurements.

4. Sulfur dioxide results from ADS and TFR samples are not statistically equivalent; ADS > TFR.
5. Total ammonium results from TFR samples are equivalent to those from FP samples. ADS sample analyses for total ammonium are not equivalent to FP sample results; (ADS < FP).
6. Total ammonium plus ammonium results are equivalent for the ADS and FP samples.

Overall, the study showed good agreement among the three multicomponent sampler results and the TDLAS results for daily samples. However, a revised method for calculation of TFR, HNO_3 measurements was necessary to obtain agreement. Additional comparisons of the sum of daily samples with the weekly sample, done only for the ADS, indicated a change of nitrite to nitrate over time with resultant potential under-estimation of HNO_2 and over-estimation of HNO_3 and total nitrate. Similar TFR and FP comparison data were not available.

Disclaimer

The research described in this article has not been subjected to Agency review. Therefore, it does not necessarily reflect the views of the Agency and no official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

References

1. J. F. Walling, "The Utility of Distributed Air Volume Sets When Sampling Ambient Air Using Solid Adsorbents," Atmos. Environ. 20 (1986) 51-57.

2. J. F. Walling, J. E. Bumgarner, J. D. Driscoll, C. M. Morris, R. E. Riley, and L. H. Wright, "Apparent Reaction Products Desorbed from Tenax used to Sample Ambient Air," Atmos. Environ. 18 (1984) 855-859.

3. R. L. Seila, "Non-Urban Hydrocarbon Concentrations in Ambient Air North of Houston, Texas," U. S. Environmental Protection Agency, EPA-600/3-79-010, February 1979.

4. R. A. Rasmussen, Personal Communication, Oregon Graduate Center; 19600 N. W. Walker Road, Beaverton, Oregon.

5. F. F. McElroy, V. L. Thompson, D. M. Holland, W. A. Lonneman, and R. L. Seila, "Cryogenic Preconcentration-Direct FID Method for Measurement of Ambient NMOC: Refinement and Comparison with GC Speciation," JAPCA 36 (1986) 710-714.

6. K. G. Anlauf, P. Fellin, H. A. Wiebe, H. I. Schiff, G. I. MacKay, R. S. Braman, and R. Gilbert, "A Comparison of Three Methods for Measurement of Atmospheric Nitric Acid and Aerosol Nitrate and Ammonium," Atmos. Environ. 19 No. 2 (1985) 325-333.

7. K. T. Knapp, J. L. Durham, and T. G. Ellestad, "Pollutant Sampler for Measurements of Atmospheric Acidic Dry Deposition," Environ. Sci. Technol. 20 (1986) 633-637.

8. J. L. Durham, T. G. Ellestad, L. Stockburger, K. T. Knapp, and L. L. Spiller, "A Transition-Flow Reactor Tube for Measuring Trace Gas Concentrations," JAPCA 36 (1986) 1228-1232.

9. M. Possanzini, A. Febo, and A. Liberti, "New Design of High Performance Denuder for the Sampling of Atmospheric Pollutants," Atmos. Environ. 17 (1983) 2605-2610.

10. J. E. Sickles, II, L.L. Hodson, E. E. Rickman, Jr., M. L. Saeger, K. L. Hardison, A. R. Turner, S. K. Sokol, and E. D. Estes, "Sampling and Analytical Methods Development for Dry Deposition Monitoring," Final Report on EPA Contract Number 68-02-4079, in preparation.

11. Director, Methods Development and Analysis Division, MD-78A, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711.

12. W. A. McClenny, T. A. Lumpkin, J. D. Pleil, K. D. Oliver, D. K. Bubacz, J. W. Faircloth, and W. H. Daniels, "Canister-Based VOC Samplers," proceedings of EPA/APCA Symposium on Measurement of Toxic Pollutants, 27-30, April 1986, Raleigh, NC.

13. C. W. Spicer, M. W. Holdren, L. E. Slivon, R. W. Coutant, M. E. Graves, D. S. Shadwick, W. A. McClenny, J. D. Mulik, and T. R. Fitz-Simons, "Intercomparison of Sampling Techniques for Toxic Organic Compounds in Indoor Air," proceedings of EPA/APCA Symposium on Measurement of Toxic Pollutants, 27-30, April 1986, Raleigh, NC.

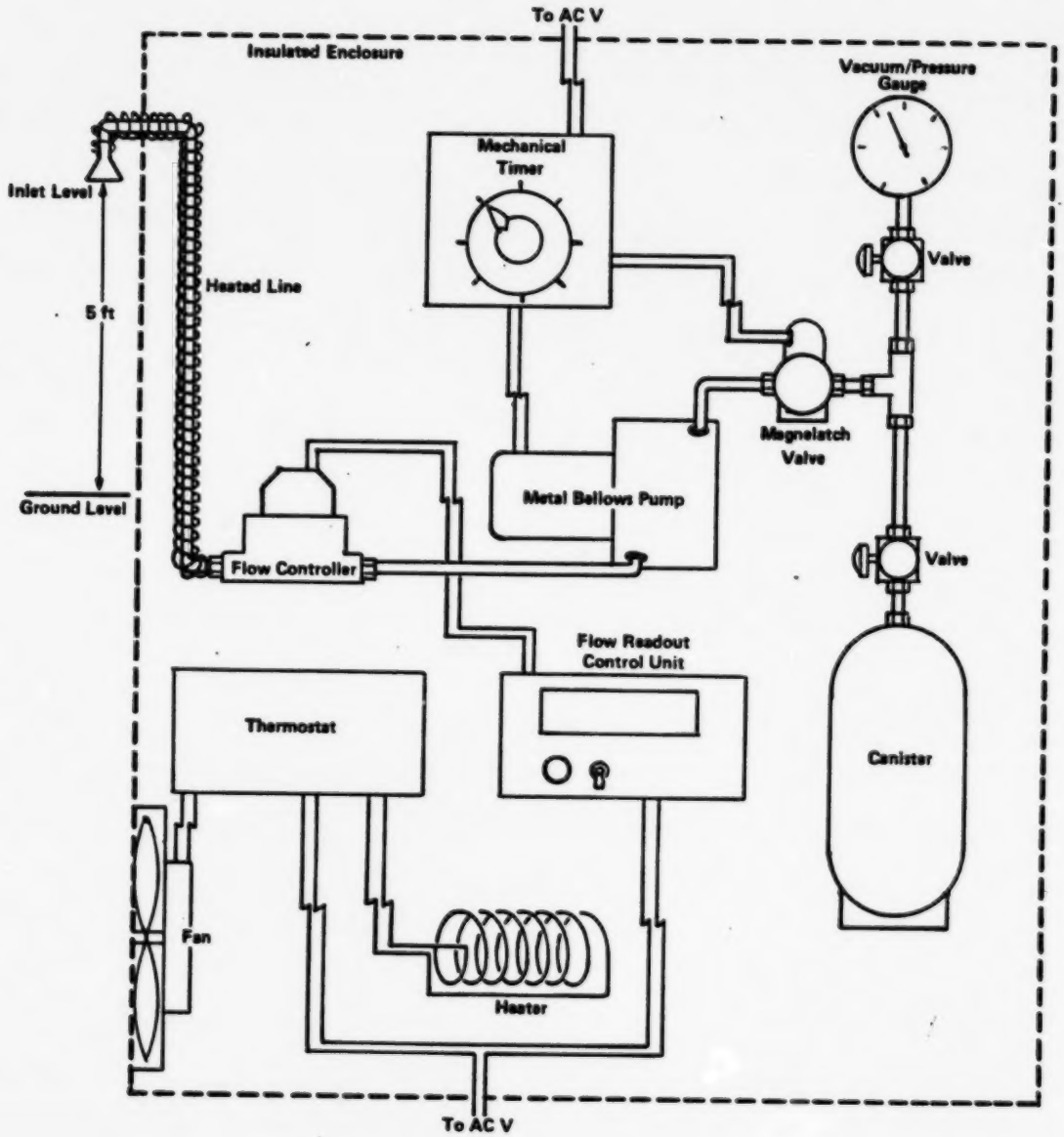

Figure 1. K-type sampler configuration.

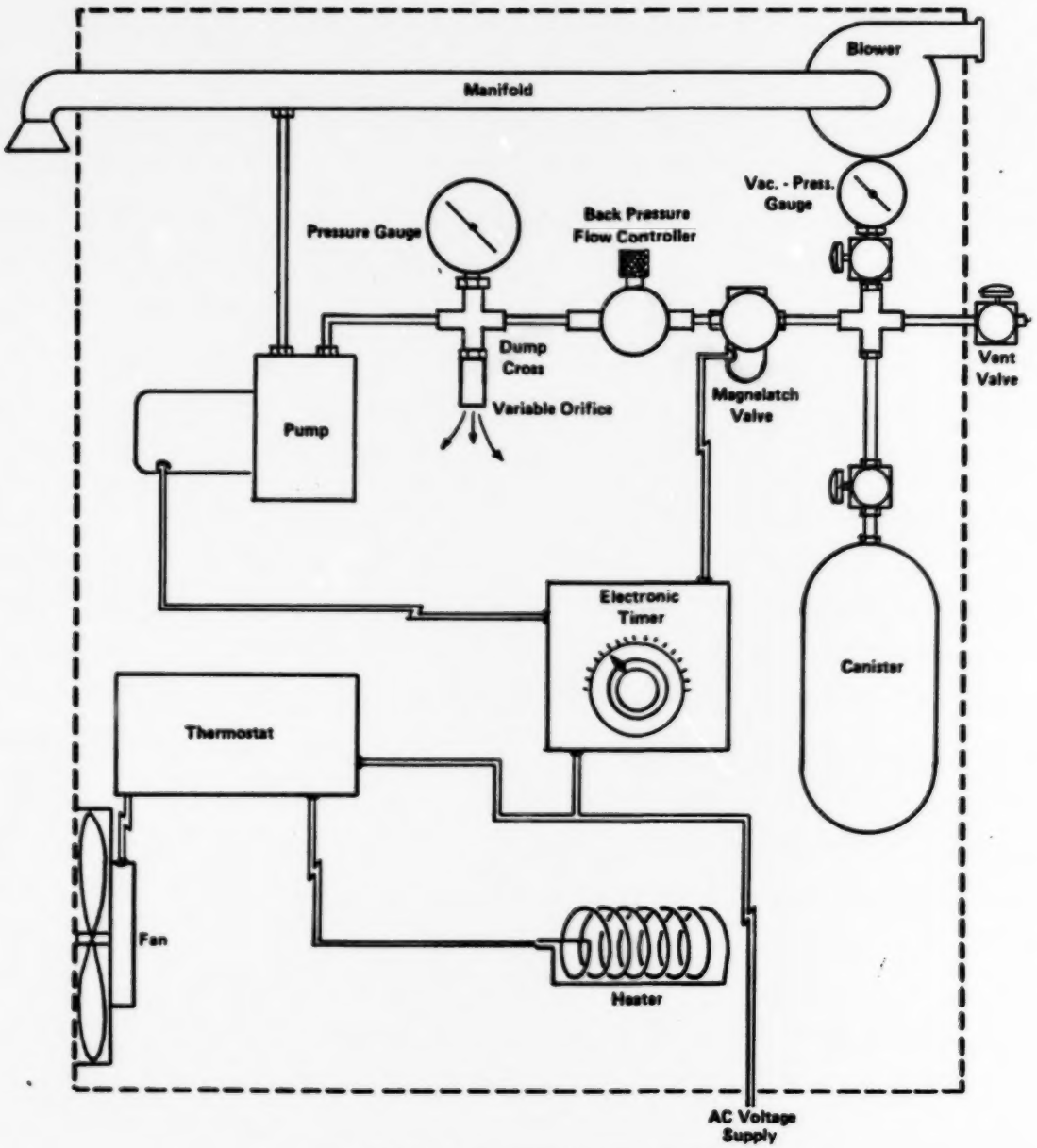

Figure 2. R-type sampler configuration.

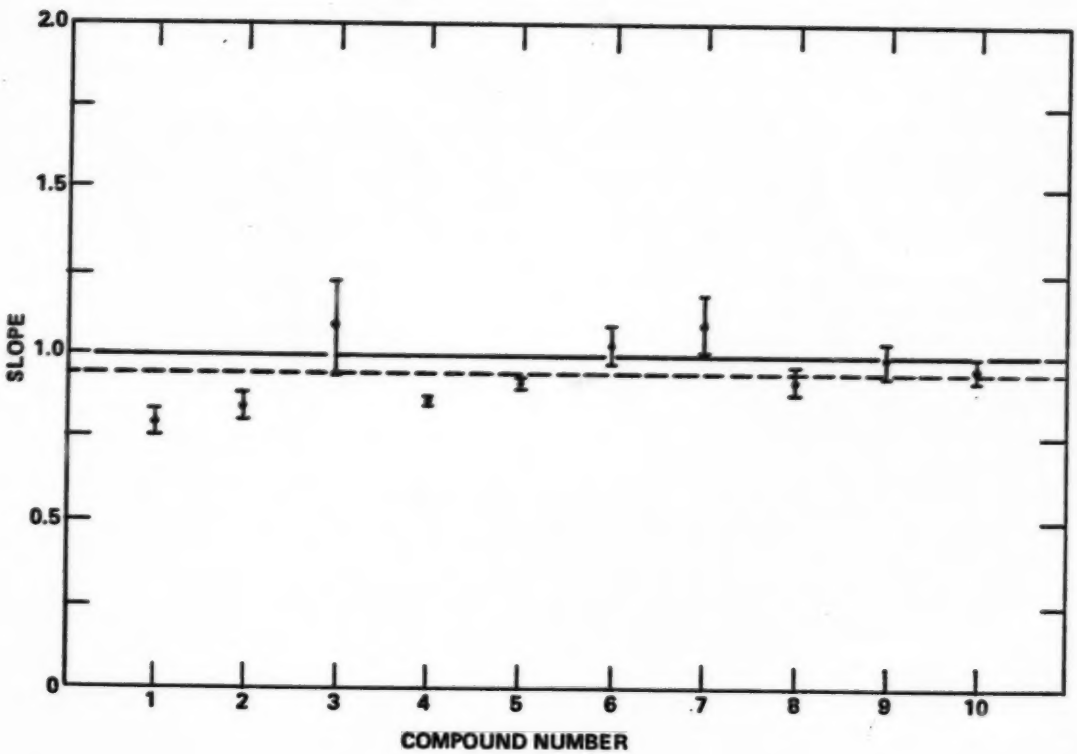

Figure 3. Tenax distributed air volume and canister slope plus and minus one standard error from the linear regression of Tenax mean vs. canister mean.